

FLUID INCLUSIONS IN MARTIAN SAMPLES: CLUES TO EARLY CRUSTAL DEVELOPMENT AND THE HYDROSPHERE; Philip E. Brown, Department of Geology and Geophysics, University of Wisconsin, Madison, WI, 53706.

Fluid inclusions (FI's) in natural materials have provided unique and crucial evidence for understanding many terrestrial geologic processes (see {1} for extensive overview). They are unique because they provide the only direct sample of any fluid phase (silicate melt, supercritical fluid, liquid, gas) present during some portion of the history of the sample. FI's have a wide range of sizes ($<1\mu$ to $>100\mu$) but most commonly are $<30-50\mu$ in size and must be $>2-5\mu$ to be studied with a light microscope. They are preserved as imperfections within mineral grains, may be equant to highly irregular in shape, may contain 0-3+ separate fluid phases at room temperature, 0-5+ solid species (0 or 1 most common), and were trapped either during original growth of the mineral or during the healing of microcracks later in the mineral's or rock's development. A wide range of microanalytical techniques are available to characterize both compositional and pressure-volume-temperature (P-V-T) properties of the inclusion contents. Such laboratory analysis permits extrapolation back to the conditions at the time of trapping and often provides the crucial bit(s) of evidence to resolve larger questions.

Major questions about Mars that could be illuminated by examining fluid inclusions in Martian samples include (1) the nature, extent and timing of development (and decline) of the hydrosphere that existed on the planet, and (2) the evolution of the crust. Fluid inclusion analyses of appropriate samples (see below) could provide critical data to use in comparison with data derived from analogous terrestrial studies.

Solid rock samples returned from Mars could well contain a variety of inclusions that record information both from the time of the rocks formation as well as later events that have occurred to and around the sample. Magmatic rocks, either intrusive or extrusive, will contain now largely solid inclusions that represent the bulk(?) magma composition at various times in the crystallization of the sample. In basaltic compositions (low angle flank slopes; Olympus Mons?, Alba Patera?) olivine is the most propitious host mineral for magmatic inclusions; in more silicic compositions (steeper slopes; Elysium Mons?), quartz, if present, provides the best host for liquid/gas inclusions. In addition to melt inclusions, these same samples (especially the more silicic ones) are likely to contain trapped, largely fluid, inclusions that preserve the volatile phase present during the crystallization or cooling process. This volatile phase may have evolved directly from the magma during cooling, may be "groundwater" present at the site of magmatic activity and moved in response to thermal convection, or a combination of the two. [Lunar samples contain solid melt inclusions but no liquid inclusions, presumably reflecting the anhydrous nature of the melts and the lack of a hydrosphere during lunar development.] The presence of polar water- and carbon dioxide-containing "icecaps" on Mars as well as the abundant evidence for widespread liquid water early in the geologic history of Mars strongly suggest that appropriate samples will contain fluid inclusions. Radiometric age dating of the same samples would address the absolute timing of major (or minor) hydrothermal activity and could be extended to deal with the timing of surficial (or near surface) hydrologic processes.

The development and maturation of the Martian crust would, in light of evidence for a hydrosphere, result in thermally driven convection cells of dominantly aqueous fluids adjacent to shallow intrusive igneous bodies. Terrestrial

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analogs would include the Skaergaard Intrusion in Greenland {2} and many porphyry-hosted copper deposits of the southwest U.S. {3}. Convecting aqueous fluids leave definite light stable isotopic and geochemical signatures as well as abundant fluid inclusions. Intrusive igneous rocks may be exposed at the surface by major tectonic processes coupled with erosion, by large impact excavations, or by more local uplift and exposure (such as caldera formation).

Sample requirements for a Martian return mission are not too stringent for this proposed study. Any solid rock that can be thin sectioned provides a potential host material (whether it has usable inclusions is another matter). Fluid inclusions are commonly studied in doubly polished (top and bottom) chips or plates that may be thin section thickness (30μ) or up to 0.5mm or more depending on the grain size and clarity of the minerals. Rocks from anywhere on Mars would be welcome but the best samples would come from rifts (Valles Marineris) and fractures on the flanks of, or from the caldera rims of, the large volcanic edifices (i.e. Olympus Mons, Tharsis Ridge, Elysium Planitia bulge). Another interesting area would be near the polar regions where the regolith and upper crust are likely saturated with a (frozen) fluid phase. Nearby igneous activity could melt the trapped fluid and allow it to be preserved as fluid inclusions.

For this study, sample handling and return restrictions are unlikely to be as restrictive as the needs of other investigators. The main constraint is that the samples not be subjected to excessively high temperatures. An aqueous fluid inclusion trapped at elevated pressure and temperature will commonly consist of liquid "water" and water vapor at room temperature. Heating (such as is done in the laboratory to fix P-V-T data for the inclusion) results in moderate pressure increases up to the liquid-vapor homogenization temperature followed by a sharp increase in pressure with continued heating because the inclusion is effectively a fixed volume system. This increased pressure can rupture the inclusion; precise limits are dependent on size, shape, and composition as well as the host material. Qualitatively, the behaviors of other common phases are the same but different species and mixtures (i.e. CO₂) will have their own pressure response to increased temperature. Therefore as long as the collected samples do not undergo more extreme P-T conditions than they have been subjected to on the Martian surface, the information that they presently contain will make it back to the laboratory.

In summary, appropriate samples returned from the Martian surface will likely contain fluid inclusions that will yield compositional as well as P-V-T data for a range of igneous and hydrothermal processes. In concert with other studies, these trapped fluids provide a unique and potentially critical piece of the puzzle of understanding Martian crustal evolution.

{1} Roedder, E. (1984) Fluid Inclusions, Reviews in Mineralogy Vol 12, 644p.

{2} Taylor, H.P. and Epstein, S. (1963) J. Petrol., 4, 51-74.

{3} Nash, J.T. and Theodore, T.G. (1971) Econ. Geol., 66, 385-399.